

## **30-Year satellite record reveals contrasting Arctic and Antarctic decadal sea ice variability**

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### **Abstract**

A 30-year satellite record of sea ice extents derived mostly from satellite microwave radiometer observations reveals that the Arctic sea ice extent decreased by  $0.30 \pm 0.03 \times 10^6 \text{ km}^2/10 \text{ yr}$  from 1972 through 2002, but by  $0.36 \pm 0.05 \times 10^6 \text{ km}^2/10 \text{ yr}$  from 1979 through 2002, indicating an acceleration of 20% in the rate of decrease. In contrast, the Antarctic sea ice extent decreased dramatically over the period 1973–1977, then gradually increased. Over the full 30-year period, the Antarctic ice extent decreased by  $0.15 \pm 0.08 \times 10^6 \text{ km}^2/10 \text{ yr}$ . The trend reversal is attributed to a large positive anomaly in Antarctic sea ice extent in the early 1970's, an anomaly that apparently began in the late 1960's, as observed in early visible and infrared satellite images.

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**Table 1.** Monthly and Annual Multiyear Averages  $a$  [ $10^6 \text{ km}^2$ ], Trend Estimates  $b$  [ $10^6 \text{ km}^2/10\text{yr}$ ] and Their Root Mean Square Errors  $\sigma_b$  [ $10^6 \text{ km}^2/10\text{yr}$ ] for Both the Full 30 (31)-Year Period 1973(72)–2002 and for Just the 24-Year Period (1979–2002)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann.
<b>Arctic</b>													
$a_{1972-2002}$	14.46	15.26	15.40	14.77	13.51	12.02	9.81	7.58	6.95	8.84	11.00	13.03	11.87
$b_{1972-2002}$	-.24	-.20	-.27	-.36	-.36	-.31	-.35	-.29	-.38	-.32	-.25	-.26	-.30
$\sigma_{b1972-2002}$	$\pm 0.05$	$\pm 0.05$	$\pm 0.05$	$\pm 0.06$	$\pm 0.05$	$\pm 0.04$	$\pm 0.07$	$\pm 0.07$	$\pm 0.08$	$\pm 0.07$	$\pm 0.06$	$\pm 0.05$	$\pm 0.03$
$b/a$ [%]	-1.7	-1.3	-1.8	-2.4	-2.7	-2.6	-3.5	-3.9	-5.4	-3.7	-2.3	-2.0	-2.5
$a_{1979-2002}$	14.40	15.20	15.30	14.62	13.35	11.93	9.73	7.52	6.85	8.73	10.94	12.97	11.78
$b_{1979-2002}$	-.32	-.24	-.29	-.32	-.25	-.38	-.47	-.41	-.48	-.36	-.36	-.36	-.36
$\sigma_{b1979-2002}$	$\pm 0.06$	$\pm 0.07$	$\pm 0.06$	$\pm 0.08$	$\pm 0.08$	$\pm 0.05$	$\pm 0.09$	$\pm 0.11$	$\pm 0.13$	$\pm 0.11$	$\pm 0.08$	$\pm 0.07$	$\pm 0.05$
$b/a$ [%]	-2.2	-1.6	-1.9	-2.2	-1.9	-3.2	-4.9	-5.4	-7.0	-4.1	-3.2	-2.8	-3.0
<b>Antarctic</b>													
$a_{1973-2002}$	5.08	3.14	4.03	6.75	10.06	13.23	15.81	17.59	18.27	17.87	15.68	10.21	11.52
$b_{1973-2002}$	-.36	-.24	-.13	-.06	-.06	-.23	-.18	-.19	-.06	-.07	-.12	-.05	-.15
$\sigma_{b1973-2002}$	$\pm 0.11$	$\pm 0.08$	$\pm 0.10$	$\pm 0.13$	$\pm 0.13$	$\pm 0.14$	$\pm 0.11$	$\pm 0.10$	$\pm 0.11$	$\pm 0.10$	$\pm 0.11$	$\pm 0.13$	$\pm 0.08$
$b/a$ [%]	-7.1	-7.7	-3.2	-0.9	-0.6	-1.7	-1.1	-1.1	-0.3	-0.4	-0.8	-0.5	-1.2
$a_{1979-2002}$	4.86	2.98	3.90	6.67	9.96	13.09	15.71	17.48	18.23	17.83	15.64	10.15	11.42
$b_{1979-2002}$	.00	.04	.19	.21	.28	.08	.01	0.03	0.04	.05	-.04	.12	.09
$\sigma_{b1979-2002}$	$\pm 0.13$	$\pm 0.08$	$\pm 0.10$	$\pm 0.15$	$\pm 0.15$	$\pm 0.14$	$\pm 0.09$	$\pm 0.08$	$\pm 0.09$	$\pm 0.09$	$\pm 0.09$	$\pm 0.16$	$\pm 0.06$
$b/a$ [%]	0.1	1.3	5.0	3.2	2.8	0.6	0.8	0.2	0.2	0.3	-0.2	1.2	0.8

interannual variability in the number of Arctic cyclones [e.g., Maslanik *et al.*, 1996]. The 365-day running mean of the daily anomalies suggests a dominant interannual variability of about 5 years (Figure 1a).

[10] Monthly and annual trends for both the Arctic (1972–2002) and Antarctic (1973–2002) are summarized in Table 1, which also includes trends for the SMMR/SSMI period (1979–2002). For the Arctic, all months have negative trends and the magnitude of the trend is greater in September, the month of minimum ice extent, than in March, the month of ice maximum. This results in an increase in the average amplitude of the 6-month seasonal variation of about  $0.3 \times 10^6 \text{ km}^2$  over the 31-year period; this is less than the  $0.5 \times 10^6 \text{ km}^2$  reported earlier for the period 1979–1999 [Vinnikov *et al.*, 2002]. The trend magnitudes for the 31-year period range from a maximum of  $0.38 \times 10^6 \text{ km}^2/10\text{yr}$  in September to a minimum of  $0.20 \times 10^6 \text{ km}^2/10\text{yr}$  in February. The trend line for the 31-year Arctic period (1972–2002) has a slope of  $-0.30 \pm 0.03 \times 10^6 \text{ km}^2/10\text{yr}$ , while that for 1979–2002 has a slope of  $-0.36 \pm 0.05 \times 10^6 \text{ km}^2/10\text{yr}$ , indicating a 20% greater trend for the 24-year period. The slope for the 24-year period is close to the  $-0.33 \pm 0.06 \times 10^6 \text{ km}^2/10\text{yr}$  value reported by Parkinson and Cavalieri [2002] for 1979–1999 and to the  $-0.32 \pm 0.04 \times 10^6 \text{ km}^2/10\text{yr}$  value reported by Björge *et al.* [1997] for 1978–1995.

[11] For the SH, the linear trend for the 30-year period is  $-0.15 \pm 0.08 \times 10^6 \text{ km}^2/10\text{yr}$ , in sharp contrast with the positive trend of  $0.11 \pm 0.04 \times 10^6 \text{ km}^2/10\text{yr}$  obtained by Zwally *et al.* [2002] for the 20-year period 1979–1998. The addition of the years 1973–1975 creates the overall negative trend. From 1973 through 1977 the annual mean ice cover decreased by almost  $2 \times 10^6 \text{ km}^2$  (Figure 1b). From 1977 through 2002 there is a gradual recovery at the rate of  $0.10 \pm 0.05 \times 10^6 \text{ km}^2/10\text{yr}$ .

[12] The SH trends by month (Table 1) have also changed significantly, with the highest magnitude trend ( $-0.36 \pm 0.11 \times 10^6 \text{ km}^2/10\text{yr}$ ) for the 30-year period occurring in January (summer) and all trends for the 30-year period showing negative signs, as in the Arctic. In contrast, most trends for the last 24 years were positive,

with the maximum trend ( $0.28 \pm 0.15 \times 10^6 \text{ km}^2/10\text{yr}$ ) occurring in May (autumn).

#### 4. Conclusions

[13] Daily, monthly, and annual trends for three decades of Arctic and Antarctic sea ice extents have been generated utilizing a statistical technique that does not assume stationarity of the time series [Vinnikov *et al.*, 2002]. The resulting sea ice extent anomalies resemble anomalies for the period 1973–2000 published previously for the Antarctic (see Figure 2.16 in IPCC [2001]), but differ substantially from those published for the Arctic (see Figure 2.14 in IPCC [2001]), although both show negative overall trends. The reason for the Arctic differences during the early part of the period 1973–2000 is apparently the result of the IPCC [2001] study using different historical data sets in combination with the more current satellite sea ice data records. Additionally, there may have been differences in the method of data set blending, but this was not explained or referenced in IPCC [2001]. The time series presented in this paper are considered to be more consistent, because our primary source of data is satellite observations, using the blended ice extent data from NIC only to match the satellite time series and to fill gaps in the satellite records.

[14] The NH anomalies show a predominant period of 5 years, similar to what was reported by Cavalieri *et al.* [1997] for 1978–1996. This 5-year period falls within the broad spectral peak centered at 4.2 years obtained from an analysis of sea ice extent, area, and the Length of Day (LOD) index, used as a proxy for the El Niño/Southern Oscillation (ENSO) [Gloersen, 1995]. Regional Arctic sea ice variations result from atmospheric circulation changes and in particular from ENSO and North Atlantic Oscillation (NAO) events [Deser *et al.*, 2000; Maslanik *et al.*, 1996; Mysak *et al.*, 1996; Parkinson, 2000]. Patterns of Arctic surface air temperature changes and trends [Rigor *et al.*, 2000] are consistent with regional changes in sea ice extent [Deser *et al.*, 2000]. A dominant mode of Arctic variability is the Arctic Oscillation (AO), and its strong positive phase during the 1990s may account for much of the recent decrease in Arctic ice extent. The AO explains more than

half of the surface air temperature trends over much of the Arctic [Rigor et al., 2000].

[15] In contrast to the NH, the SH sea ice cover decreased dramatically over the period 1973–1977, then increased at an overall rate of  $0.10 \pm 0.05 \times 10^6 \text{ km}^2/10\text{yr}$  from 1977 through 2002. This trend reversal results from the large positive anomaly in Antarctic sea ice extent observed in the early 1970's (Figure 1b). The decreasing positive anomaly from 1973 to 1976 (Figure 1b) is part of a longer period sea ice anomaly that began in the late 1960's and was observed in early visible and infrared satellite images [Streten, 1973; Sissala et al., 1972; Zwally et al., 1983b]. From 1968 to 1973 there was an increase in ice extent, preceding the 1973–1976 decrease (see Figure 5 in Zwally et al. [1983b]). The large positive sea ice extent anomaly in 1973 has been associated with a “cold” ENSO event [Streten, 1973; Carleton, 1989]. The fact that this short-term positive anomaly results in a negative trend for the 30-year period emphasizes the need for a longer time series extended back in time using, for instance, available visible and infrared satellite measurements.

[16] In addition to ENSO events, longer term atmospheric variations have been identified including appreciable changes in SH tropospheric circulation at middle and high latitudes since the 1970s [Hurrell and Van Loon, 1994]. These changes are also evident in the trend toward more positive SH annular mode indices over the last few decades [Thompson and Wallace, 2000], with the transition from mostly negative to mostly positive indices occurring during the 1970s. The more positive indices are associated with stronger westerlies and cooler temperatures over much of Antarctica [Thompson and Solomon, 2002]. Exactly how this trend is related, if at all, to the increase in sea ice extent since the 1970's remains to be determined.

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